

Normative Human Gait Databases

Use Own One or Any Available

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Abstract

The human gait is uniquely characterized by its kinematics and kinetics. These characteristics are routinely used to analyse and evaluate both the normal and pathological gait. A lot of clinical studies, dealing with quantitative human gait analysis and published all around the world, use the normative gait databases to evaluate pathological gait, but only a few of them describe their background. However, this is an important factor as it makes the analysis objective and directly influences the interpretation of motion analysis results. There is also a lack of comparative studies that evaluate and compare such databases, acquired within different laboratories considering the age, typology and/or gender of included healthy/normal subjects. Therefore, the human gait analysis was made on a group of young healthy subjects and then, based on their kinematical parameters, a normative gait database of anatomical joint angles was created. Moreover, our database was compared with three different world available databases which were also compared each other. To compare individual kinematical parameters of all here included databases, a methodology based on testing of statistical hypotheses was used. Acquired results confirmed that the laboratories should spend some time to get their own normal human gait data to create own normative database in order to maximize the gait analysis objectivity rather than to use databases of another laboratories even if equipped with identical motion analysis system.

Keywords

Human Gait Analysis; Normative Gait Database; Anatomical Joint Angles

Introduction

The development of experimental techniques and the analysis of acquired results in the field of science have stimulated the fast progress of natural sciences during the last decades. This development caused also the continual increase of knowledge and theories about processes in living human organisms. The trends influence also the studies of human motion and its related problems. Therefore, scientific research studies should make effort to improve and clarify motion

problems by means of the newest technical as well as scientific knowledge.

The study of human motion provides details to evaluate individual motion activities based on knowledge of functional anatomy, physiology, neurophysiology, biomechanics and many other disciplines dealing with human motion tasks and allows obtaining, analysis and evaluation of motion disorders that result from different anomalies, deformities and/or pathology of body segments. During the history of human motion analysis systems, it becomes standard to collect data and creates the databases of subject motion characteristics. The collected healthy subjects' data are then used to prepare normative motion databases. The majority of clinics and gait laboratories create their own normative gait databases to ensure objectivity of later pathological gait data evaluation process.

One of the main tasks of the gait analysis is to determine whether a motion is physiological or if it differs and how much it differs from the normal values. To do this, it is necessary to use the "correct" normative gait database. As there are several gait databases available all around the world, we have compared four of them in this study. The reason was to find out the differences among them and to point out the possible risks during the pathological gait data interpretation.

Material

There were four normative human gait databases included in our comparative study. These kinematical databases consisted of sagittal planes' anatomical joint angles. The first database was created in our laboratory using the newly developed marker-free analysis system Mafran. The data in this database were collected from ten young healthy male adult subjects in the average age of 24.8 years (SD 2.18) and average height 178.54 cm (SD 5.4). The subjects without known pathology were asked to walk at their natural speed

during the laboratory tests. The subjects' normal data have been used to define the borders of 95% confidence interval of hip flexion/extension, knee flexion/extension and ankle plantar/dorsal flexion angles as it is shown in Fig. 1.

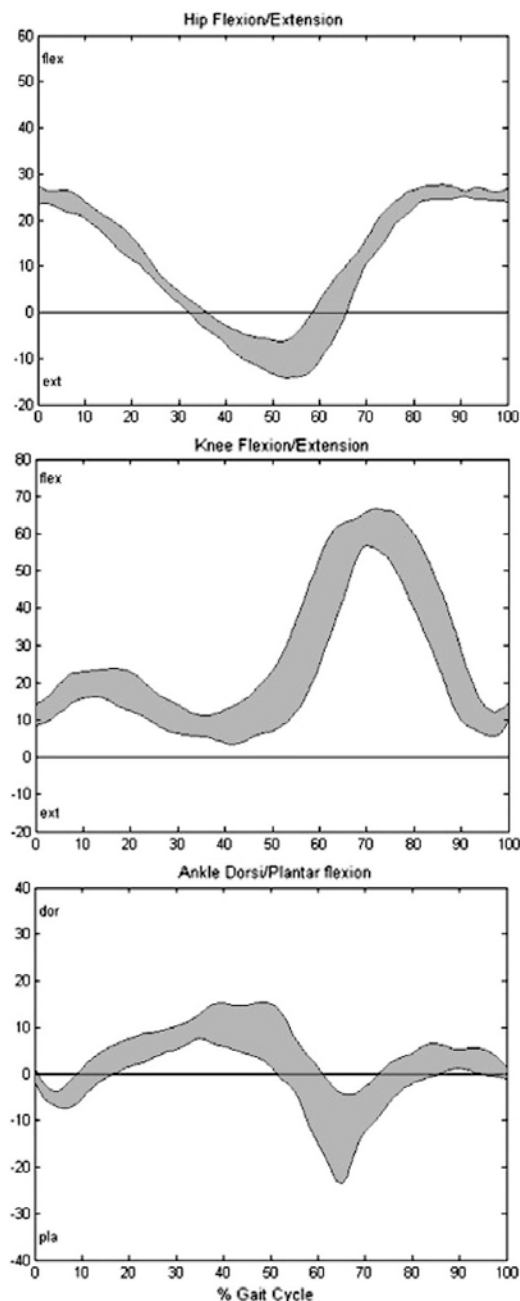


FIG. 1 NORMATIVE DATABASE OF ANATOMICAL JOINT ANGLES IN SAGITAL PLANE

The other databases of anatomical joint angles were the databases of three world laboratories published and available on the webpages of CGA Normative Gait Database. The first, was the database of nine young adult subjects (6 females and 3 males) acquired at the Musgrave Park Hospital, Belfast, N. Ireland by the team of Dr. Richard Baker using the six cameras system Vicon 370 version 2.5. The next one, was the

database of Jeremy Linsell from LimbFitting Centre Dundee, Scotland who performed the measurements on the group of five healthy young adult subjects; each of which was captured five times using the five cameras system Vicon VX. The third normative database was from Hong Kong Polytechnic University, obtained by Chris Kirtley who used a group of ten young adult subjects and analysed the gait with the six cameras system Vicon 370. The figure 2 shows the mean values and the standard deviations of kinematical parameters obtained in all above mentioned databases.

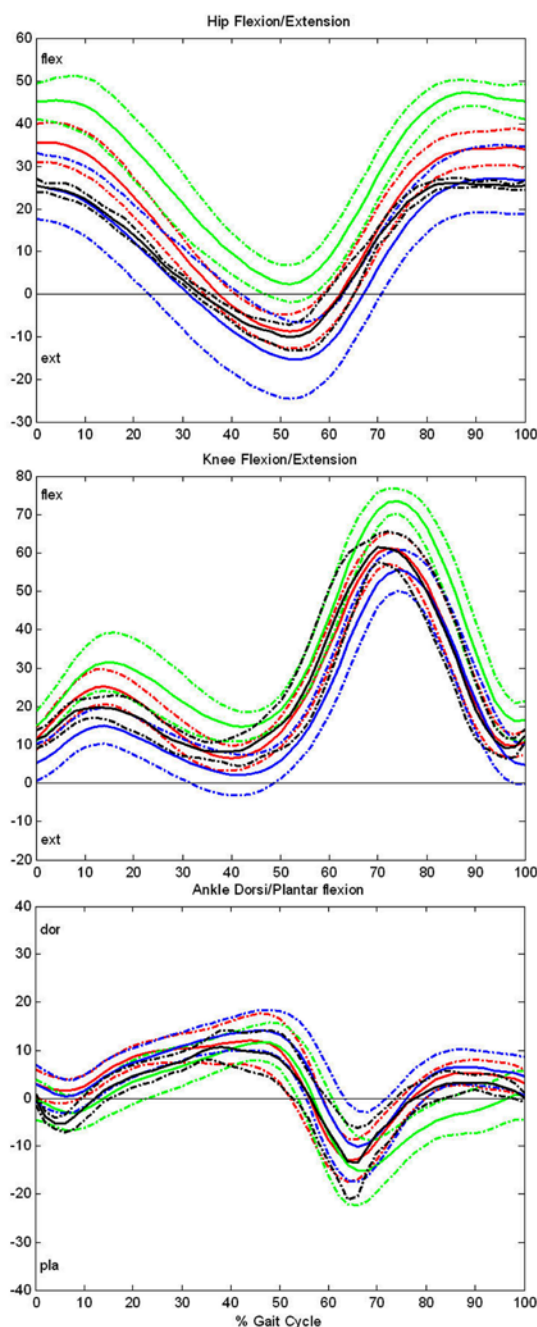


FIG. 2 THE NORMATIVE HUMAN GAIT DATABASES OF FOUR GAIT LABORATORIES. COLORS: RED – BELFAST, GREEN – DUNDEE, BLUE – HONG KONG, BLACK – MAFRAN

Methods

To test the normative gait databases compatibility, the statistical methods were taken based on comparison of individual statistical characteristics. Such comparison is charged by particular variability of values from which they were calculated. This is why the simple differentiation of two compared parameters cannot be used and it is necessary to verify whether the difference is statistically significant or not.

When testing the data similarity, we tested if the averages of the unknown base patterns, let say ξ_1 and ξ_2 , are identical. The testing process was performed using following sequence of steps.

1. Specify a zero hypothesis, meaning that the dispersions of two unknown base patterns are equal.

$$\sigma_1^2 = \sigma_2^2, \quad (1)$$

2. Choose the significance level (α), in such way that the random difference will be greater than critical value. The most frequently used values are $\alpha=0.05$ or $\alpha=0.01$. The deviations greater than critical values are then classified as statistically significant at the particular significance level.

3. Test the zero hypothesis. Here, using two sample dispersions s_1^2 and s_2^2 , the decision whether the unknown dispersions of base patterns σ_1^2 and σ_2^2 can be considered as equal is made. To determine it, the mutual F-test for $\alpha=0.05$ was done. The parameter F was calculated as:

$$F = \frac{s_1^2}{s_2^2}, \quad (2)$$

where F is the test criterion and has F – distribution with $k_1=n_1-1$ and $k_2=n_2-1$ degrees of freedom. Then, the critical values $F_{\alpha/2, k_1, k_2}$ and $F_{1-\alpha/2, k_1, k_2}$ for particular k_1 , k_2 and α must be found in the statistical tables. Then, these values are compared with test criterion and if:

$$F_{\alpha/2, k_1, k_2} < F < F_{1-\alpha/2, k_1, k_2}, \quad (3)$$

the zero hypothesis is accepted, otherwise the zero hypothesis is rejected.

4. Choose the test criterion of mean values equality and evaluate the result.

A) In the case, the zero hypothesis was accepted, then the test criterion is:

$$t = \frac{|\bar{x}_1 - \bar{x}_2|}{\sqrt{\frac{n_1 s_1^2 + n_2 s_2^2}{n_1 + n_2 - 2}}} \sqrt{\frac{n_1 n_2}{n_1 + n_2}}, \quad (4)$$

and has the Student distribution and $k=n_1+n_2-2$ degrees of freedom. The critical value t_α is given by the tables for Student distribution at the chosen level of significance α and with the particular degrees of freedom. Then, if:

$$t_\alpha \geq |t|, \quad (5)$$

the averages of base patterns are considered as equal, which means that the normative gait data at the chosen significance level α are considered as equal. However, if the critical value is less than calculated value of test criterion then the difference of normative gait database at the chosen significance level is considered as statistically significant.

B) In the case, the zero hypothesis was rejected, then the test criterion will be calculated as follows:

$$t = \frac{|\bar{x}_1 - \bar{x}_2|}{\sqrt{\frac{s_1^2}{n_1 - 1} + \frac{s_2^2}{n_2 - 1}}}, \quad (6)$$

and the critical value:

$$t_\alpha^* = \frac{t'_\alpha \frac{s_1^2}{n_1 - 1} + t''_\alpha \frac{s_2^2}{n_2 - 1}}{\frac{s_1^2}{n_1 - 1} + \frac{s_2^2}{n_2 - 1}}, \quad (7)$$

where t'_α is the table value of Student distribution for particular α and $k=n_1-1$ degrees of freedom and t''_α is the table value of Student distribution for particular α and $k=n_2-1$ degrees of freedom.

The test criterion is then compared with critical value as given by the following expression:

$$t_\alpha^* > t, \quad (8)$$

If the expression (8) is true, then the compared normative human gait data are considered as equal at the chosen significance level α . Otherwise, the difference of normative human gait data at the chosen significance level α is considered as statistically significant.

Using this method, the equality of individual normative gait databases was continuously tested. The validation of two sample averages equality at the level of significance $\alpha=0.05$ was marked using the next transcription:

$$\xi_{iXY} = \begin{cases} 1 & \text{if } \xi_{iX} = \xi_{iY}, \\ 0 & \text{if } \xi_{iX} \neq \xi_{iY}, \end{cases} \quad (9)$$

where index i means anatomical joint angle of tested

database (H for hip, K for knee, A for ankle) and X and Y marks tested sample averages (B for data from Belfast, D for data from Dundee, H for data for Hong Kong and M for data from our system Mafran). The value 1 means that the data are equal at the chosen significance level α and value 0 means that the data are unequal at the chosen significance level α , i.e. the data are significantly different.

Results

The six pairs of tests were performed, where each normative gait database was compared with one another. As first, our database has been compared with database from Belfast. The comparative study showed that the normative hip flexion/extension angles differs at the chosen level of significance ($\alpha=0.05$) until the 34% of gait cycle. Then, the normative data are equal from 36 to 78 % of gait cycle. Again, the data differs during the rest of swing phase until the end of gait cycle. The results are shown in Fig. 3., where the difference in databases is marked as a point at the zero line and the equality as a vertical line.

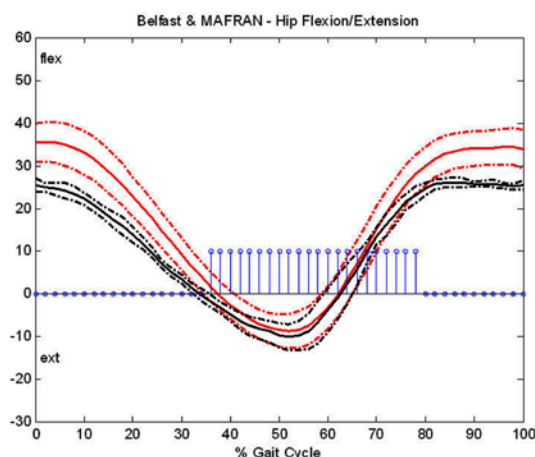


FIG. 3 THE RESULTS OF COMPARATIVE TEST OF HIP FLEXION/EXTENSION IN MAFRAN AND BELFAST DATABASES

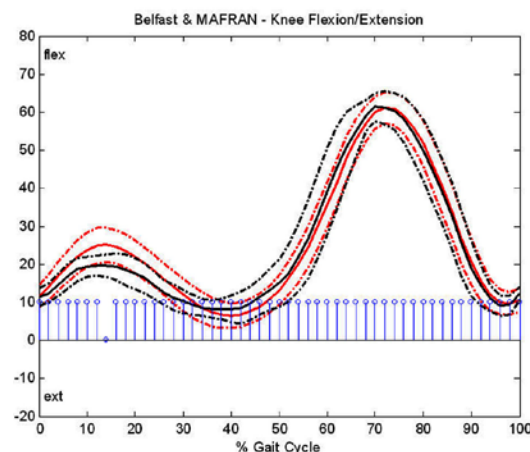


FIG. 4 THE RESULTS OF COMPARATIVE TEST OF KNEE FLEXION/EXTENSION IN MAFRAN AND BELFAST DATABASES

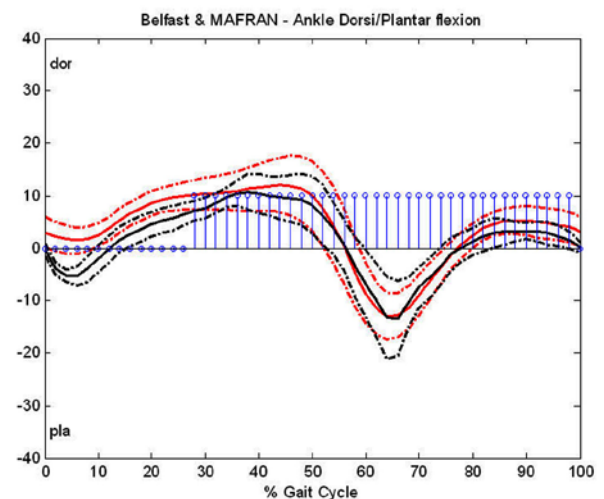


FIG. 5 THE RESULTS OF COMPARATIVE TEST OF ANKLE PLANTAR/DORSAL FLEXION IN MAFRAN AND BELFAST DATABASES

Then, our normative gait database was compared with database from LimbFitting Centre of Dundee. The normative hip flexion/extension angles differed at whole gait cycle at the level of significance $\alpha=0.05$. The normative knee flexion/extension angles are equal up to 6% of gait cycle and then the data differed until the beginning of the end of stance phase. Again the equality of data was confirmed from 42% to 68% of gait cycle at the chosen level of significance ($\alpha=0.05$). Then, the data differed until the end of the gait cycle. The most fit was found in ankle plantar/dorsal flexion angles, where the data were equal at the level of significance $\alpha=0.05$ except of short interval 74-90%.

The third comparison done with the database from Hong Kong showed that our normative knee flexion/extension angles are completely equal with those from Hong Kong. The hip flexion/extension angles were equal from 12% to 40% and from 74 % to 98% of gait cycle. As well the ankle plantar/dorsal flexion angles were equal except of 2-8% of gait cycle at the significance level $\alpha=0.05$.

Similarly, the world databases were compared. The results of all statistical comparisons are summarized in following tables. The table 1 summarizes the overall percentage of equality in hip flexion/extension.

TABLE 1 THE EQUALITY OF HIP FLEXION/EXTENSION IN COMPARED NORMATIVE GAIT DATABASES

	Mafran	Belfast	Dundee	Hong Kong
Mafran	-	43.14%	0.00%	100.00%
Belfast	43.14%	-	0.00%	23.53%
Dundee	0.00%	0.00%	-	0.00%
Hong Kong	100.00%	23.53%	0.00%	-

The only identical values were statistically proved between databases Mafran and Hong Kong. The table

2 summarizes the overall percentage of equality in knee flexion/extension angles.

TABLE 2 THE EQUALITY OF KNEE FLEXION/EXTENSION IN COMPARED NORMATIVE GAIT DATABASES

	Mafran	Belfast	Dundee	Hong Kong
Mafran	-	98.04%	35.29%	54.90%
Belfast	98.04%	-	33.33%	33.33%
Dundee	35.29%	33.33%	-	0.00%
Hong Kong	54.90%	33.33%	0.00%	-

Here the database Mafran and Belfast are identical with no statistically significant difference. The table 3 summarizes the overall percentage of equality in ankle plantar/dorsal flexion.

TABLE 3 THE EQUALITY OF ANKLE PLANTAR/DORSAL FLEXION IN COMPARED NORMATIVE GAIT DATABASES

	Mafran	Belfast	Dundee	Hong Kong
Mafran	-	70.59%	82.35%	90.20%
Belfast	70.59%	-	54.90%	100.00%
Dundee	82.35%	54.90%	-	74.51%
Hong Kong	90.20%	100.00%	74.51%	-

Again, all the databases are significantly different except Belfast and Hong Kong.

Discussion

Identification of deviations in a patient's gait from normal movement patterns is one of the main objectives of clinical gait analysis. Here, a critical component is the availability of well-matched normative databases. Researchers usually refer to published data or develop their own normative databases, but such databases may significantly differ. It is difficult to assess differences in normative gait databases due to the high-dimensionality and temporal nature of the various kinematic waveforms. However, the differences were also confirmed also by our results of sagittal plane kinematics. The summary of our comparative study is presented in the table 4.

TABLE 4 THE AVERAGED EQUALITY OF NORMATIVE GAIT DATABASES

	Average	SD
Mafran vs Belfast	70.59%	27.45
Mafran vs Dundee	39.24%	41.31
Mafran vs Hong Kong	81.70%	23.72
Belfast sv Dundee	29.41%	27.66
Belfast vs Hong Kong	52.29%	41.61
Dundee vs Hong Kong	24.84%	43.02

The highest similarity of here compared normative databases was found between Mafran and Hong Kong normative gait databases, but even if these databases

represent the most fitted values from here included kinematical patterns, it is still only 81.70%, i.e. there is an statistically significant difference at the $\alpha=0.05$.

Conclusions

The four normative human gait databases of anatomical joint angles were compared in this study. The results showed that only the data from our laboratory and the data from Hong Kong fit more than 80%. All the other normative gait databases have very small equality, mostly less than 50% even if the databases were created from the data of similar groups of young healthy subjects.

When thinking of which normative gait database should be used, it is necessary to realize that the differences can be caused by various factors including motion analysis system used to acquire the gait data; used marker set; methodology of kinematics parameters calculation; characteristics of included healthy subjects; gender, age and the number of included subjects as well as the operating personnel.

The achieved results convinced us that there are significant differences between databases developed in different laboratories and that there is probably no generally usable normative human gait database despite of relatively long history of human gait analysis. Due to this, it is supposed that the creation of own normative gait database is still the best way to ensure the most objective clinical gait analysis.

ACKNOWLEDGMENT

Result presented in this work were obtained with the support of the national grant KEGA 005UPJS-4/2012 and preparation of the grant VEGA 1/0652/14.

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